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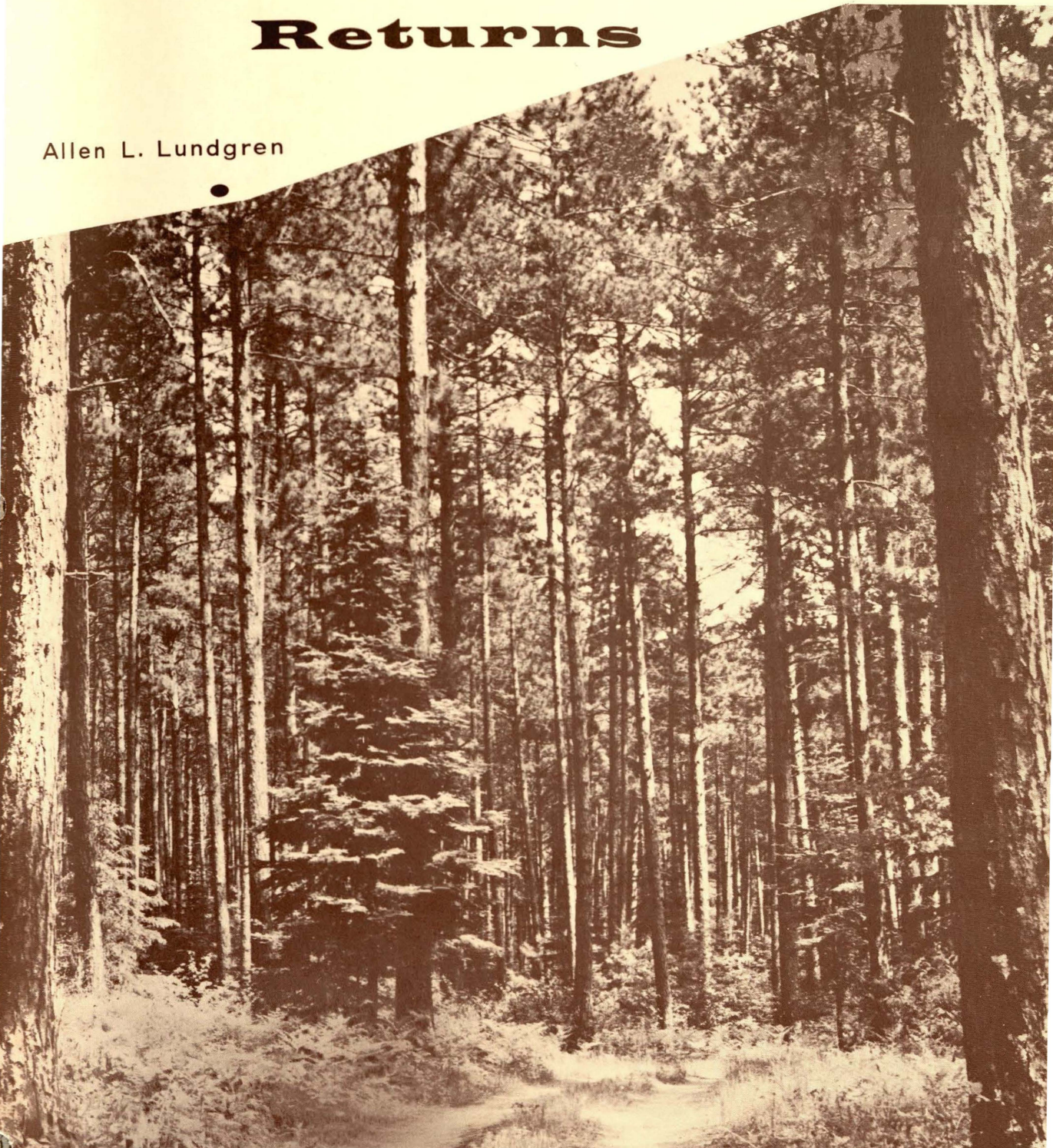
U. S. FOREST SERVICE
RESEARCH PAPER LS-18
AUGUST 1965

X R. 233 X 2321

Thinning Red Pine for High Investment Returns

Allen L. Lundgren



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Thinning Red Pine for High Investment Returns

by Allen L. Lundgren

Red pine (*Pinus resinosa* Ait.), a favored timbered species in the Lake States, is well-suited to intensive, even-aged silviculture. Comparatively free of serious damage by insects and diseases, it responds well to thinning (fig. 1). However, because red pine can be thinned in many ways to grow a number of salable products, the forest manager may have difficulty deciding just how a stand should be thinned to best attain the owner's goals.

In both public and private forestry an important goal is to earn the highest possible return on capital invested in growing timber; this indicates that capital resources are being used efficiently. To meet this goal, foresters growing red pine must know how silvicultural practices and other management conditions affect investment earnings.

Of the many factors involved, some, such as thinning practices and rotation lengths, can be controlled by the forest manager. Others, such as the amount of capital invested, initial stocking, and site selection, may be under his control only at certain times. Still others, such as stumpage prices and the cost of capital, may be beyond his control. Thus the forest manager can influence investment returns to some extent, but only within certain limits.

This paper is written for the professional forest land manager. It explains how two factors that can be controlled, thinning practices and rotation ages, affect investment returns from growing red pine. It demonstrates that, under almost any conditions, investment returns are highest if stands are thinned regularly to 90 square feet of basal area per acre, the lowest density evaluated. It shows how financial rotations, which must be estimated in evaluating thinning alternatives, vary widely with stand conditions, investment alternatives, costs, and prices, and suggests financial rotation ages for certain stand conditions commonly found in the Lake States.

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FIGURE 1. — Red pine responds well to a variety of thinning practices and can be cut for many products.

Note: Dr. Lundgren is an Economist on the staff of the Lake States Forest Experiment Station. His headquarters are at the Station's Laboratories and Main Office, which are maintained by the Forest Service, U.S. Department of Agriculture, on the St. Paul Campus in cooperation with the University of Minnesota.

The Thinning Alternatives Examined

The volume growth of red pine stands varies with site and stand conditions. On a given site, early growth can be controlled to some extent by the initial spacing of trees (through planting or early thinning) and by release and other cultural practices. These will determine the density (basal area) and stocking (number of trees) during the early years in an established stand. Once a stand is established, its future growth can be greatly influenced by thinning (fig. 2).

The early choice of a thinning schedule is important, because each thinning sets in motion a new sequence of growth that in the future can be altered only within certain limits. The influence of any past thinning practices can never be eliminated completely by subsequent thinnings. Thus, any proposed program of thinning should be evaluated over an entire rotation to insure that early thinnings do not create a less desirable stand for the future.

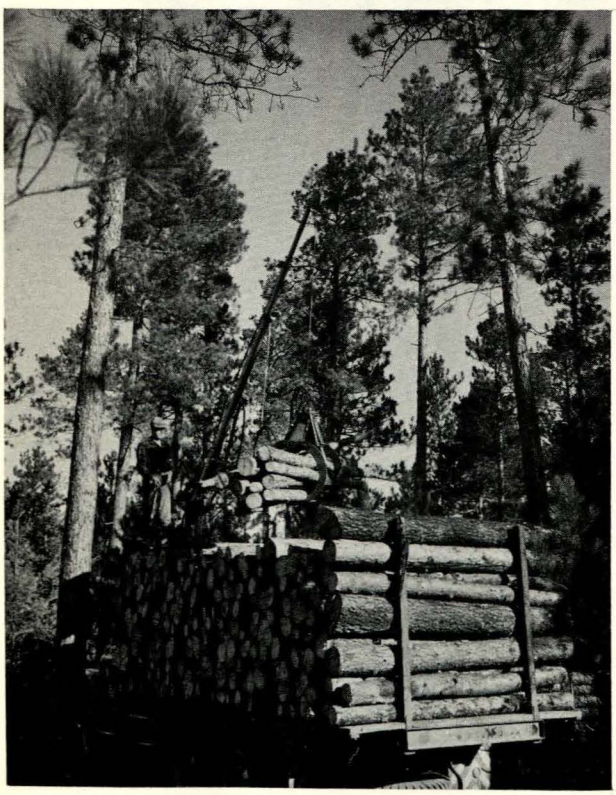

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FIGURE 2. — Early thinning in red pine produces pulpwood and other small products such as posts and poles.

The density left after each thinning, the method of thinning, the thinning interval, and the age of the first thinning all affect future volume yields (fig. 3). All can be controlled by the forest manager.

This study evaluates only the basal area left after thinning and its effect on investment returns. Because there is almost no limit to the different kinds of red pine stands and the ways in which they can be thinned, the following examples were selected to represent a wide range of initial stand conditions and thinning programs:

Site index: 45, 50, 55, and 60.

Basal area before thinning at age 25: 60, 90, 120, 150, and 180 square feet per acre.

Number of trees before thinning at age 25: 400, 800, 1,200, and 1,600 per acre.

Rotation ages: 25 to 165 years.

Alternative rates of return: 2 to 8 percent.

Regeneration costs: $0 to $80 per acre.

Markets: (1) Cordwood only
(2) Cordwood and sawtimber with constant stumpage prices
(3) Cordwood and sawtimber with higher prices for larger trees

Many variations in density left after thinning were evaluated: (1) Maintaining a constant basal area of 60, 90, 120, or 150 square feet per acre throughout the rotation, and (2) varying the basal area throughout the rotation by allowing it to increase, decrease, or vary irregularly. However, basal areas of 60 square feet after thinning, and initial densities of more than 90 square feet of basal area with only 400 trees per acre are not reported here because they were not well supported by field data. Thinning schedules that allowed the basal area to vary throughout the rotation also were dropped. Only rarely did these give higher investment returns than constant basal areas; furthermore, they would be more complicated to apply in the field.

Therefore, the thinning alternatives considered here are constant levels of basal areas from 90 to 150 square feet per acre maintained throughout the rotation.

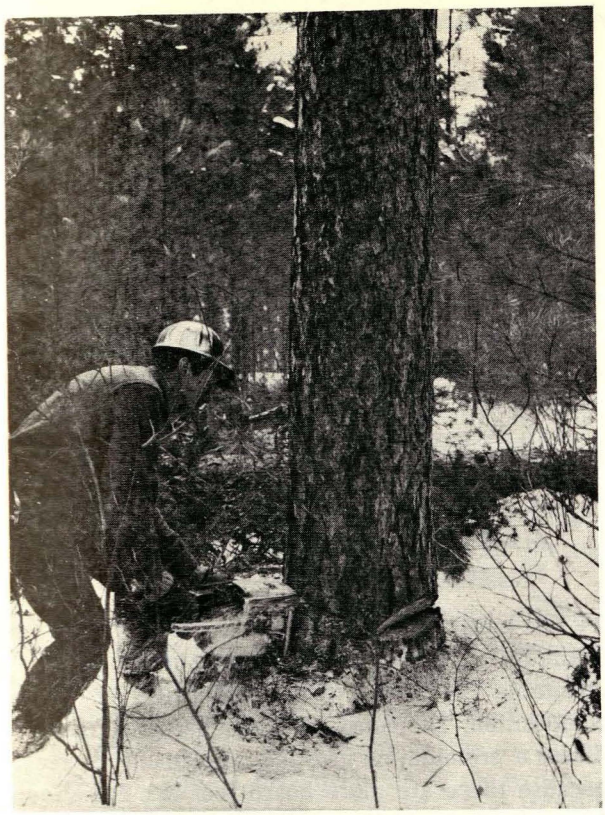

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FIGURE 3. — Red pine stands thinned to low densities (90 square feet) grow faster in diameter and produce saw log thinnings 20 years earlier than stands maintained at high densities (150 square feet).

The thinning method chosen was one commonly used: thinning from above-and-below. With this method both large and small trees are cut at each thinning so that the average stand diameter is not changed by thinning and the remaining stand of trees is well-spaced.[1] Stands were thinned every 10 years, beginning at age 25 if the basal area at that time was above the desired level.

For each site, stand condition, and thinning schedule to be evaluated, cordwood and board-foot volume yields from thinnings and from final harvest cuts at each age were computed. These were developed from the basal area growth and total cubic-foot volume yields which were estimated from growth equations based on permanent sample plots and reported by Buckman (1962). Total cubic-foot volumes were converted to cordwood volumes at 9.7 cords per thousand cubic feet (from Buckman's (1962) cubic-foot and cordwood volume ratio estimates).[2] Average stand diameters at each age were estimated for each schedule from basal area growth and known numbers of trees. Conversion factors were applied to cubic-foot yields to get board-foot yields.[3] These factors, varying with average stand diameter and height, were estimated from data given by Gevorkiantz and Olsen (1955). In all, more than 500 volume yield tables were constructed and evaluated.

Because growth data for stands younger than 25 years are not yet available in sufficient detail, initial stand conditions are described in terms of the basal area and number of trees per acre at age 25 before thinning. The range of initial basal areas and numbers of trees studied covers most variations likely to occur at that age in Lake States stands. Information on the growth of large-diameter trees is limited, so a rotation was ended whenever trees would exceed 25 inches in diameter. This restriction had no impact on thinning decisions, and only rarely on rotation age decisions.

The following merchantability standards were set:

1. All stands averaging less than 4.6 inches diameter breast high (d.b.h.) are nonmerchantable.
2. In stands averaging 4.6 inches or larger in d.b.h., all trees can be cut as cordwood.
3. In stands 9.1 inches or larger, all trees can be cut as saw logs.
4. Yields of less than 2 cords or 1,000 board feet per acre are nonmerchantable.

Future yields are assumed to be known with certainty, and are not reduced for risk of catastrophic loss by fire or other agents.

In summary, the thinning alternatives to be examined are constant levels of stand density from 90 to 150 square feet of basal area per acre to be left after each thinning at 10-year intervals over a range of sites, initial stand conditions, rotation ages, costs, prices, and alternative rates of return.

[1] *In this paper the average stand diameter is the diameter breast high (d.b.h.), outside bark, of the tree of average basal area.*

[2] *Rough cords in trees 3.6 inches d.b.h. and larger to a 3.0-inch top d.i.b. (diameter inside bark).*

[3] *International ¼-inch rule in trees 7.6 inches d.b.h. and larger to a 6.0-inch top d.i.b.*

Evaluation of Investment Alternatives

Land expectation values (LEV) are used to evaluate alternative thinning schedules and rotations under various costs, prices, and stand conditions.[4] This measure of investment return is the present value (the value at the beginning of a rotation) of the discounted net income expected from an investment. Each thinning schedule and rotation age under each set of cost, price, and other conditions is considered a separate investment alternative. For each investment, all costs and incomes during one rotation are discounted back to the time of stand establishment. Subtracting discounted costs from discounted incomes gives the present value of an investment for one rotation. Multiplying this present value by a special interest rate factor, which allows for a land value left at the end of the rotation, gives the LEV.[5] The thinning schedule resulting in the highest LEV earns the highest return (net income) on capital invested during the rotation. All returns reported here are before income taxes.

In discounting costs and incomes, the alternative rate of return should be used. This is the rate of compound interest that could be earned on the money or capital if it were invested elsewhere. It is the price of the capital used in the investment. The alternative rate used should be realistic, because in calculating the present value it is assumed, in effect, that all extra investment funds and all income from growing red pine can be reinvested at this rate.[6] We will assume that the alternative rate, the cost of capital, is known.

Incomes from thinnings and from final harvest cuts are estimated for each thinning alternative by multiplying volume yields by expected stumpage prices. Three basic stumpage price schedules are considered:

1. *Constant cordwood price* — where only cordwood can be sold at a constant stumpage price regardless of stand characteristics.
2. *Constant sawtimber price* — where both cordwood and sawtimber can be sold at a constant price per cord and per thousand board feet.
3. *Varying sawtimber price* — where both cordwood and sawtimber can be sold, but prices vary with average stand diameter (d.b.h.) according to the following formulas:

   $(½ dbh — 1) per cord
   $(dbh + 5) per thousand board feet
   $2 per cord in tops of sawtimber trees.

The constant cordwood price market places no premium on tree size, but values equally all merchantable cubic-foot volume regardless of stand composition. The constant sawtimber price market places a premium on growing large-diameter trees, because there are more board feet per cubic foot of total volume in larger diameter trees. It places a further premium on growing sawtimber sized trees because a cubic foot of wood is usually worth more as sawtimber than it is as cordwood. The varying sawtimber price market places an even higher premium on growing larger diameter trees, because cordwood prices increase $0.50 per cord and sawtimber prices $1 per thousand board feet for each one-inch increase in average stand diameter.

Although realistic for parts of the Lake States, the price schedules used are not meant to represent actual market conditions expected in growing red pine. Rather, they cover a wide range of possible prices to test the effect of extreme differences in future markets on present thinning and rotation age decisions.

Two classes of costs are considered: annual management expenses, and regeneration (stand establishment) costs (which include site preparation, planting, release, and pruning). All future costs during the rotation are discounted back to the time of stand establishment, using the specified discount rate. No distinction is made among regeneration costs. We are interested in how costs

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[4] *The merits of this and other methods of evaluating investment alternatives have been debated at great length in the literature. Those wishing more information on this are referred especially to Thomson (1942), Chapman (1950), Davis (1954), Hiley (1956), and Gaffney (1957).*

[5] *The multiplier used is* $\frac{(1+p)^n}{(1+p)^n-1}$, *where* p *is the discount rate and* n *is the rotation length in years.*

[6] *Duerr, Fedkiw, and Guttenberg (1956, pp. 4 and ff.) discuss how to determine the alternative rate of return. See also Duerr (1960, pp. 143 and ff.).*

in general will affect thinning and rotation age decisions; for this purpose it makes no difference whether a cost is a discounted release cost or a site preparation cost so long as it results in the same kind of red pine stand at a given age. Regeneration costs from $0 to $80 per acre and a range of annual expenses are considered. No other costs are included. Stumpage prices are assumed to be net of any special sales costs.

Because the rotation age affects the expectation value of the red pine timber growing investment, it must be considered even when a stand is just being established. However, in estimating a rotation age to use in evaluating a future stand the purpose is not to set one which future managers must follow. Rather, it is to insure that all foreseeable costs and incomes to the end of an investment cycle are included in the appraisal.

This analysis evaluated all possible rotation ages at 10-year intervals from age 25 to 165 years for each thinning opportunity. From these alternative ages, the one giving the highest land expectation value (LEV) was chosen as the financial rotation age, and its LEV was used as the expectation value of the thinning opportunity. By using this financial rotation, which varies from 25 to 165 years depending upon discount rates, costs, prices, and stand conditions, the highest returns obtainable from each investment opportunity are compared. If no rotation is specified, it should be understood that a given LEV is for the financial rotation age.

This financial rotation is used with the expectation that it will be the one chosen by a manager seeking the highest return on his investment. A manager with this aim would end a rotation whenever the capital in a stand left after thinning will no longer earn the alternative rate of interest that could be earned elsewhere. Unless conditions change, the rotation age set in this way is identical with that giving the highest LEV.

To evaluate the three density levels over the range of conditions examined in this paper, about 200,000 land expectation values were computed by an electronic computer, using a special program designed for this study. It would not be possible or desirable to present all these data in this paper. Instead, only the conclusions about stand density and rotation ages will be given, with a few examples as illustrations.

Effect of Stand Density On Investment Returns Under Various Conditions

Through a program of regular thinnings it is possible to control the growing space of individual trees in a red pine stand. Such thinnings are biologically and economically practical. The problem is, how much timber should be left after each thinning so as to earn the highest return on the capital invested in a stand?

For the basal area thinning levels considered here the answer is surprisingly simple. With only a few minor exceptions, thinning red pine stands back to 90 square feet of basal area per acre every 10 years will give a higher investment return over the rotation than thinning back to any higher basal area density (figs. 4 and 5). This is true regardless of the initial density and stocking of the stand, site, discount rate, costs, or stumpage prices. A few examples will illustrate these conclusions.

Let's look first at a red pine stand on a medium site, site index 50. Establishment costs of $40 per acre are expected to result in a well-spaced stand of 800 trees and 120 square feet of basal area per acre at age 25 before thinning. There are no other timber growing costs to be considered. The stand is to be managed for both cordwood and sawtimber with constant prices of $20 per thousand board feet and $2 per cord.

With a 3-percent discount rate, if the stand were thinned every year to 150 square feet of basal area per acre the land expectation value (LEV) would be only $19 per acre (fig.6). If thinned to 90 square feet the LEV would be $50. In fact, from the steepness of the line it looks as though lower basal areas would give even higher returns; however, basal areas of less than 90 square feet are not being considered here.

By the end of the rotation these differences in investment return among densities are even more striking. If this stand is thinned every 10 years and the income from thinnings invested at 3 percent (the rate earned on alternative investments),

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FIGURE 4. — This 40-year-old red pine plantation has just been thinned to 90 square feet of basal area per acre. Stands thinned regularly to this low density will earn a higher return on invested capital than stands thinned to a higher density.

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FIGURE 5. — This 40-year-old red pine plantation has just been thinned to 150 square feet of basal area per acre. Stands maintained at such high densities earn a relatively low investment return even when grown primarily for pulpwood.

by the end of the 85-year rotation the net income would be $235 per acre higher if the stand is thinned to 90 square feet rather than to 120 square feet. It would be $384 per acre more if maintained at 90 rather than 150 square feet. These are sizable differences in net investment income.

Stand conditions, costs, prices, and other factors may vary, and with them land expectation values, but the conclusion remains the same:

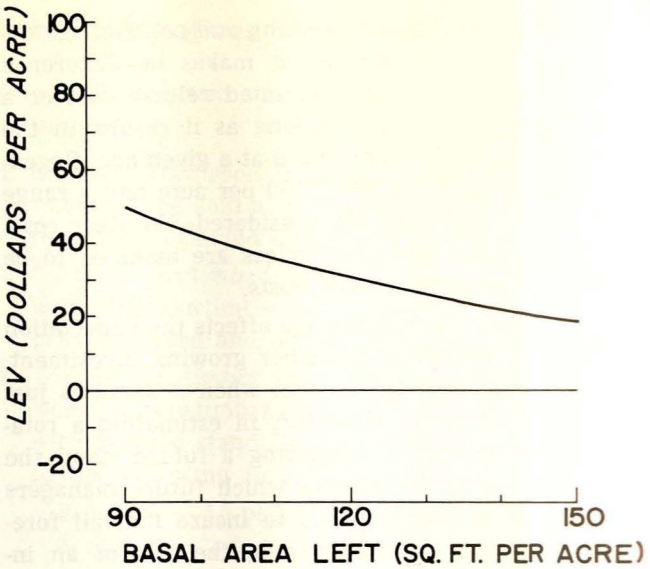

FIGURE 6. — Red pine land expectation values (LEV) are highest at low densities. Site index 50, establishment costs $40 per acre, stumpage prices $20 per thousand board feet and $2 per cord, discount rate 3 percent, 800 trees and 120 square feet per acre at age 25.

thinning to 90 square feet gives higher LEV's than thinning to any higher basal area in every type of stand under almost all conditions.

Site Index and Initial Stand Conditions

The more productive the land, as measured by site index, the higher the expectation value if management costs and stumpage prices are the same. But still, a density of 90 square feet gives the highest investment return on any site from 45 to 60 (at an index age of 50 years), the range of Buckman's (1962) growth equations (fig. 7).

Wide variations in basal area and number of trees per acre before thinning at age 25 greatly alter stand structure, but low-density management gives the highest returns (fig. 8).

Discount Rates and Costs

A change in discount rate changes expectation values, but not the conclusions (fig. 9). With any alternative rate from 2 to 8 percent, a residual basal area of 90 square feet per acre after thinning gives the highest return on investment.

Regardless of whether it costs nothing or $80 per acre to establish a stand, thinning every 10 years to 90 square feet gives a higher return on the invested capital than thinning to any higher density (fig. 10).

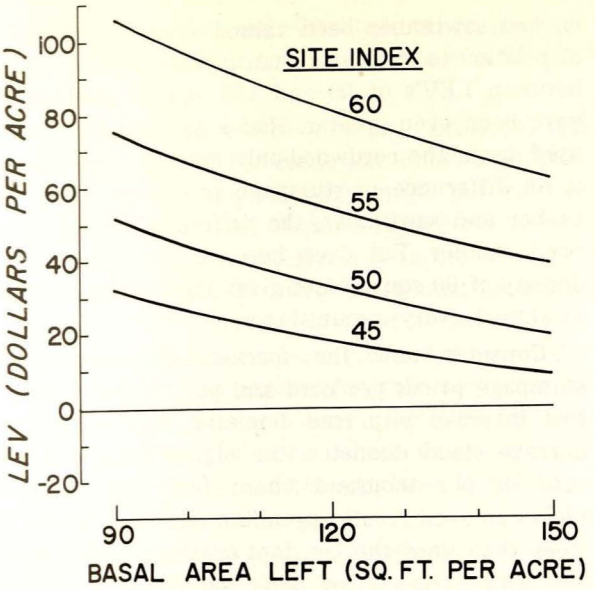

FIGURE 7. — Red pine land expectation values (LEV) are highest at low densities on all sites. Establishment costs $40 per acre, stumpage prices $20 per thousand board feet and $2 per cord, discount rate 3 percent, 800 trees and varying basal areas per acre at age 25.

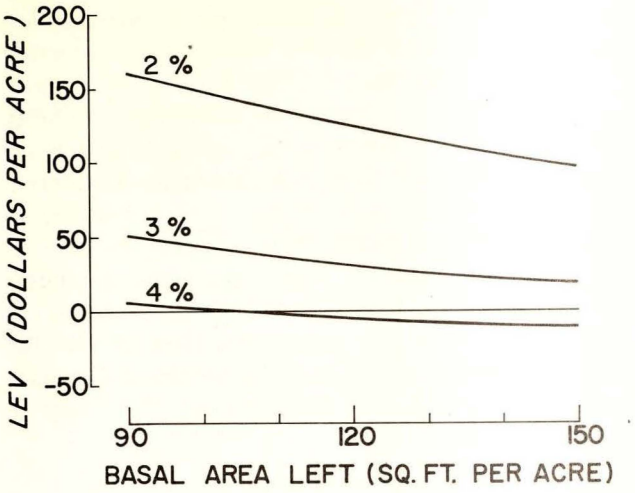

FIGURE 9. — Red pine land expectation values (LEV) are highest at low densities for a range of alternative rates of return. Site index 50, establishment costs $40 per acre, stumpage prices $20 per thousand board feet and $2 per cord, 800 trees and 120 square feet at age 25.

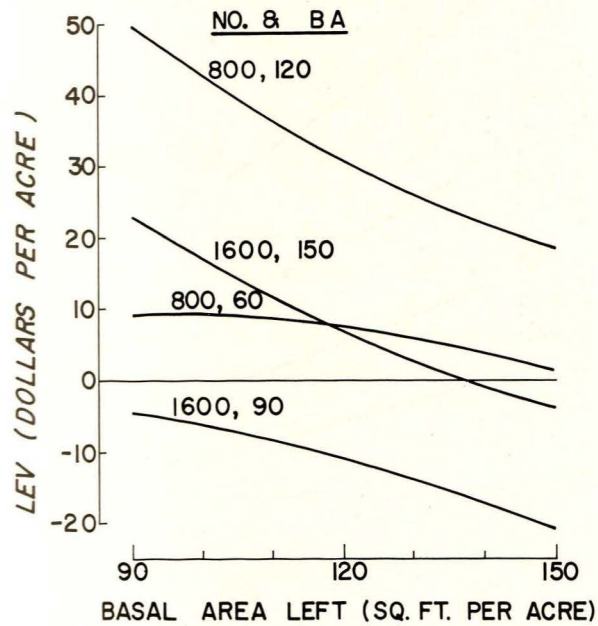

FIGURE 8. — Red pine land expectation values (LEV) are highest at low densities over a wide range of number (no.) of trees and basal area (BA) per acre before thinning at age 25. Site index 50, establishment costs $40 per acre, stumpage prices $20 per thousand board feet and $2 per cord, discount rate 3 percent.

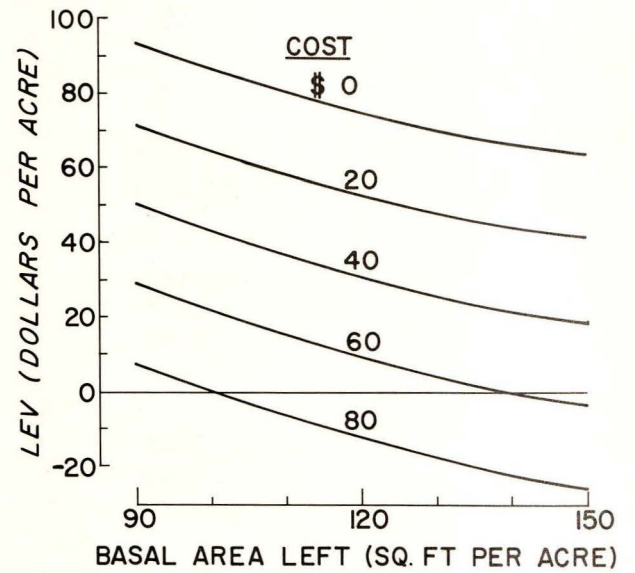

FIGURE 10. — Red pine land expectation values (LEV) are highest at low densities over a wide range of stand establishment costs. Site index 50, stumpage prices $20 per thousand board feet and $2 per cord, discount rate 3 percent, 800 trees and 120 square feet at age 25.

Similarly, if annual management expenses are the same for each density level, then subtracting a constant capitalized expense from each expectation value will not change the relative profitability of the different densities. If the costs differ for each density level, then they should be considered. But there would have to be a big difference to change the conclusions. With a 3-percent alternative rate, management expenses on the site-index-50 example would have to be 60¢ per acre higher each year at the 90 square-foot than at the 120 square-foot density level to make the 120 square feet more profitable. A difference this large is highly unlikely.

Markets

In the constant sawtimber price market, higher or lower stumpage prices per thousand board feet and per cord will not change the choice of stand density. Whether prices are $10 per thousand board feet and $1 per cord or $30 per thousand board feet and $3 per cord, thinning to 90 square feet of basal area per acre still gives higher returns than any higher density (fig. 11). At lower prices the difference in dollars per acre is smaller, but there still is a difference.

The ratio of sawtimber price per thousand board feet to cordwood price per cord used in figure 11 is 10 to 1. Had a larger ratio been used, that is, had sawtimber been valued even more highly in relation to cordwood than it was, the difference between LEV's of 90 and 150 square feet would have been even greater. Had a smaller ratio been used, as in the cordwood-only market where there is no difference in stumpage price between pole-timber and sawtimber, the difference would have been smaller. But even here, as we shall see, a density of 90 square feet gives the highest returns in almost every circumstance.

Consider now the market situation where stumpage prices per cord and per thousand board feet increase with tree diameter. The larger the average stand diameter, the higher the price per cord or per thousand board feet. This market places an even greater premium on larger diameter trees than does the constant-sawtimber-price market. Since trees grow more rapidly in diameter in stands maintained at a low density, there is an even greater advantage for thinning to low basal areas.

On site-index-60 land, for example, the LEV for 90 square feet is $72 an acre higher than for 150 square feet, using a 3-percent discount rate (fig. 12). The difference in net incomes between

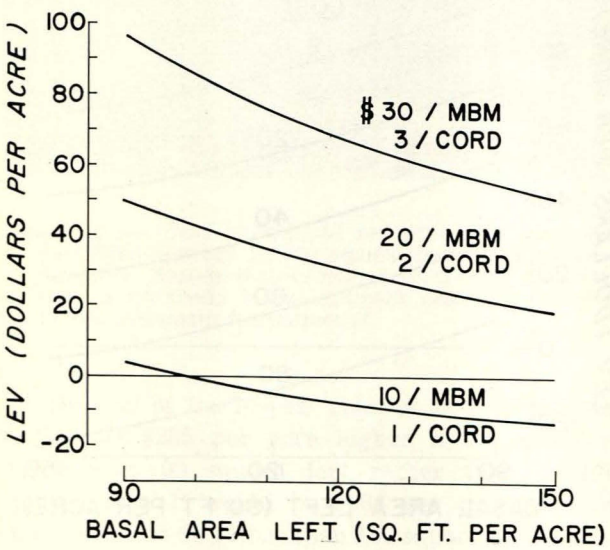

FIGURE 11. — Red pine land expectation values (LEV) are highest at low densities over a wide range of stumpage prices. Site index 50, establishment costs $40 per acre, discount rate 3 percent, 800 trees and 120 square feet at age 25.

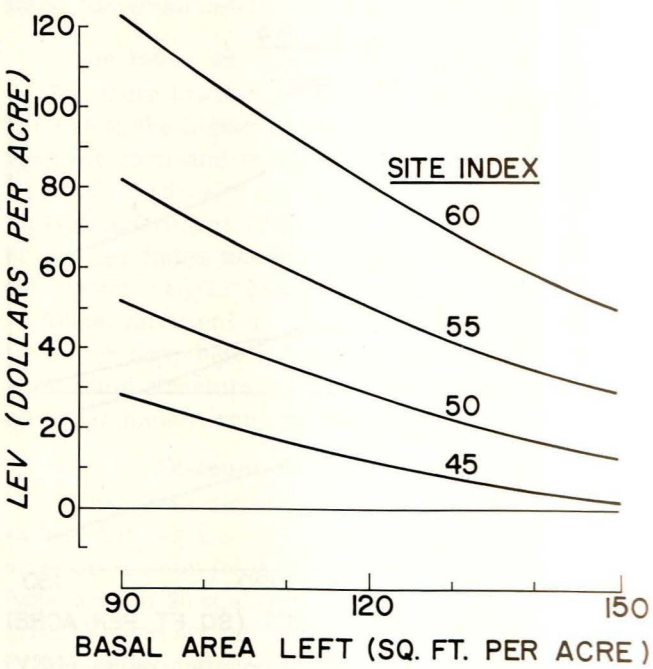

FIGURE 12. — Red pine land expectation values (LEV) are highest at low densities on all sites. Establishment costs $40 per acre, stumpage prices increase with tree diameter, discount rate 3 percent, 800 trees and varying basal areas per acre at age 25.

these two alternatives, invested at 3 percent, amounts to $1,200 per acre by the end of a 95-year rotation.

In still another potential market situation, red pine may be grown for cordwood alone. This market assumes that the stumpage price per cord is the same for any kind of stand regardless of tree size — that it makes no difference in net stumpage price whether twice as many trees must be marked and cut to get one cord of wood in one stand as in another. In many respects this is not a realistic market; yet it was chosen for this very reason. How are choices of stand density affected by such extreme market conditions, where prices are unaffected by tree size and the emphasis is on growing cubic-foot volume?

Even under these extreme conditions, a density of 90 square feet still gives the highest returns for almost all conditions (fig. 13). Exceptions occur if discount rates and costs of establishment are very low. On site index 50, for example, with $4 per cord stumpage, a discount rate of 2 percent, and no establishment costs, the LEV is $113 per acre if 120 square feet are left compared to $112 per acre if 90 square feet are left. Under these unlikely conditions the difference is only $1 per acre. With any establishment costs or with higher rates, 90 square feet would give equally high or higher LEV's than 120 square feet. If higher net stumpage prices are expected for larger diameter trees, through a reduction either in sale preparation costs or in logging costs, then low-density management will be more profitable because trees will grow faster in diameter.

We have assumed that prices will remain unchanged over the rotation. It may be, however, that they will rise at some specified rate, say 1 percent annually. Will such a rise have any effect on the choice of 90 square feet as giving the highest return on investment?

A rise in future stumpage prices of 1 percent is roughly the same as a reduction in the alternative rate of return of 1 percent.[7] As we have already seen, reducing the discount rate will not change our choice of 90 square feet of basal area to be left after thinning.

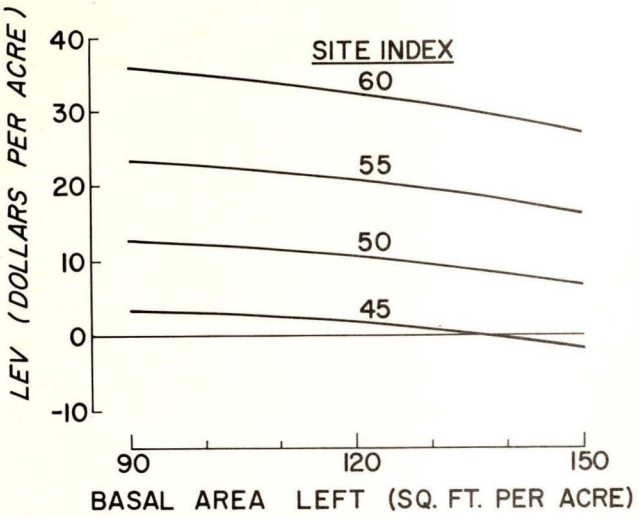

FIGURE 13. — Red pine land expectation values (LEV) in stands grown for cordwood are highest at low densities for all sites. Establishment costs $40 per acre, stumpage price $4 per cord, discount rate 3 percent, 800 trees and varying basal areas at age 25.

Timber Quality

One last price consideration remains — stumpage price variations with density. Some foresters insist that timber grown at a more open spacing — a lower density — is less valuable than timber grown at higher densities; it may have poor form, bigger knots, or other defects. They may be reluctant to thin stands back to 90 square feet of basal area per acre, fearing that diameter growth in such low-density stands will be too fast for good-quality wood.

If a general consensus emerges from the literature on this subject it is this: Conifer trees with from 6 to 8 rings per inch have about as high a specific gravity as trees of the same age that have been grown at a slower rate and thus have more rings per inch (Spurr and Hsiung 1954, Paul 1957, Ralston and McGinnes 1964). Although slow-grown trees may be more desirable in some respects, trees with from 6 to 8 rings per inch are

[7] *This approximation underestimates present values by a small percentage. The underestimate is greater for higher alternative rates of return, higher rates of price increase, and longer discount periods. The discounted value of a single return in 10 years, with prices increasing at 1 percent a year and with a 2-percent alternative rate of return, is underestimated by less than 0.1 percent. For a 2-percent price rise and a 5-percent alternative rate, the underestimate of a single value discounted over 50 years is 2.8 percent, while for prices increasing 3 percent a year and a 6-percent alternative rate of return over 100 years, it would be about 8.1 percent.*

acceptable for sawtimber and veneer logs if they meet minimum size and knot specifications (Hiley 1956, Lutz 1958, Marsh 1963).

None of the thinning schedules considered in this study produced less than 6 rings per inch. Only one schedule produced 7 rings per inch, and this only during a 20-year period in a stand on site index 60. On sites less than site index 55, thinning to 90 square feet every 10 years always gave 8 rings or more over the entire range of initial density and stocking considered here. Throughout much of their lives, most red pine stands managed at low densities grow more than 10 rings per inch. Stands managed at higher densities often grew more than 40 rings per inch (Lundgren and Wambach 1963).

On this basis there is little reason to reject the low densities proposed here because of excessive diameter growth. Nevertheless, let's see how great an increase in stumpage price would be needed to overcome any defects in open-grown trees in one of the examples already used.

Suppose timber from the stand shown in figure 11 normally sold for $20 per thousand board feet if thinned back every 10 years to 90 square feet of basal area per acre. If this stand were thinned to 120 square feet, timber would have to sell at $25 per thousand board feet just to equal expectation values from the 90-square-foot density management. Similarly, if thinned to 150 square feet, timber would have to sell at $30 per thousand board feet. Only if stumpage prices differed more than this would we be better off financially to leave a higher density after thinning.

However, if branch size were the problem, low-density stands could be pruned. Suppose that timber from these same stands can be sold for $20 per thousand board feet regardless of whether it comes from pruned stands maintained at 90 square feet or unpruned stands at 150 square feet. The present difference in expectation values is $31 per acre (fig. 11). If this stand is to be thinned to 90 square feet every 10 years, $56 per acre could be spent to prune at age 20 ($56 discounted for 20 years at 3 percent is $31), or $75 per acre to prune at age 30, or some combination of these, and still equal the investment return from managing the stand at 150 square feet of basal area per acre. Or $10 could be spent for release at age 10, $25 for the first pruning at age 20, and $25 to complete pruning at age 30, and still 90 square feet would give as high returns as 150 square feet. If pruned trees of large diameters command a higher stumpage price than unpruned trees of small diameters as one might expect, then even more could be spent on timber stand improvement.

By maintaining red pine at a low density, more can be invested in the stand to improve tree quality. The amount will, of course, vary with the site, stand condition, discount rate, and all the other variables that affect investment return.

Low-density management has the additional advantage of providing more investment flexibility. Trees grown at a low stand density can be sold at an earlier age for larger sized products. On site index 60, with 1,200 trees and 150 square feet of basal area at age 25, for example, the first sawtimber thinnings can be made at age 55 if the stand is thinned to 90 square feet every 10 years, but the first sawtimber cut is delayed until age 65 if thinned to 120 square feet, and until age 75 if thinned to 150 square feet.

Summary

From these examples, which are typical of thousands of others computed for this study, it is evident that leaving 90 square feet of basal area per acre when thinning red pine gives higher investment returns over a wide range of stand conditions, past histories of thinning, costs, prices, and discount rates than does leaving any higher basal area.

The only exception is in growing cordwood if discount rates and establishment costs are low and if larger-diameter trees do not command a higher stumpage price. Even here, however, thinning to 90 square feet gives an investment return near the maximum.

Because it creates a more flexible stand, one that under almost any foreseeable cost and market conditions will earn a higher return or at least as high a return on invested capital as a stand maintained at a greater density, thinning to 90 square feet is a good choice.

Basal Area Densities Lower Than 90 Square Feet

Information on red pine growth at densities below 90 square feet of basal area is available, but most of it is for natural stands with large numbers of trees per acre. These lower densities are not included in this paper because we are not sure how well the data fit stands with fewer trees per acre or where they are no longer reliable.

Thus with all this analysis some important questions remain unanswered. We can conclude from our analysis only that leaving *more* than 90 square feet of basal area per acre after thinning is seldom more profitable than leaving 90 square feet, the lowest density studied. So the field of choice has been greatly limited. But densities of less than 90 square feet may be even more profitable. Obviously much more needs to be learned about low-density management, particularly at low stocking levels. Until this information is available, however, we can thin stands to 90 square feet under most conditions, knowing that this will give a higher return on investment than any higher density.

Financial Rotation Age

At any time during the life of a red pine stand the rotation can be ended by clearcutting, rather than prolonged by thinning. To earn the highest investment return, the rotation should be ended when the capital invested in the land and the timber left after thinning will no longer earn the alternative rate over the next 10-year thinning interval. At this age (the financial rotation age) the stand is financially mature (fig. 14).

Estimation of Financial Rotation Age

At each thinning the rate expected to be earned over the next 10 years by the capital in land and timber left after thinning can be estimated by the following formula:

$$(1+r)^{10} = \frac{FV + LEV}{PV + LEV}$$

where r = the annual rate of value increase

FV is the future value in 10 years of the timber left after thinning

PV is the present value of the timber left

LEV is the land expectation value for growing future timber crops.[8]

Once $(1+r)^{10}$ is calculated, the annual rate of increase (r) can be obtained from interest rate tables, from the log-log scales on a slide rule, or from curved values of $(1+r)^{10}$ plotted for known interest rates (as in fig. 15).

If the expected rate of value growth after thinning (r) is higher than the rate of interest that could be earned in other investments, then the stand is thinned rather than clearcut. If the rate of

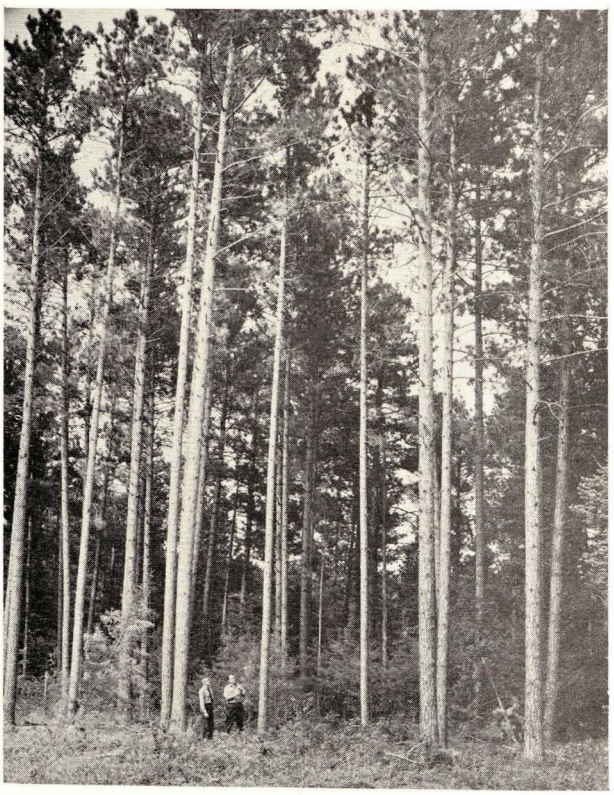

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FIGURE 14. — This 95-year-old red pine stand may still be growing in value 5 percent or more each year. When its earning rate falls below what could be earned in other investments, the stand will be financially mature and should be cut.

[8] *The LEV for the appropriate discount rate (alternative rate of return) is included to account for the cost of postponing income from future timber-growing investments on the land.*

value growth is expected to be less than could be earned elsewhere, then the stand is clearcut and the capital is invested elsewhere at the alternative rate. Figure 16 shows the value increase for a typical stand on site index 60 for alternative discount rates. The rate of increase varies with the discount rate used, because the value of the land for growing future crops of timber (the LEV) varies with the discount rate.

With a 4-percent rate as an example, at age 75 the value of the land and timber left after thinning to 90 square feet of basal area per acre is expected to increase at a compound interest rate of 5 percent annually over the next 10 years, so the stand is thinned to 90 square feet. At age 85, when the stand is examined again, it would be expected to increase over the next 10 years at slightly more than 4 percent annually, so the stand is once again thinned to 90 square feet. At age 95 the stand is expected to increase at about 3½ percent, considerably less than the 4 percent that could be earned in other investments, so the entire stand is clearcut because it is financially mature. In this stand the financial rotation is 95 years.

The financial rotation set in this way is also the one giving the highest LEV where conditions remain the same throughout the rotation.

Factors Affecting Financial Rotations

Site, initial stand conditions, stand age, and density left after thinning all affect the rate of volume growth in stands. Within these biological limits, present and future prices and the cost of establishing future stands determine the value growth. All of these factors, together with the alternative rate of return, affect the age at which a stand is financially mature, as the following tabulation shows.

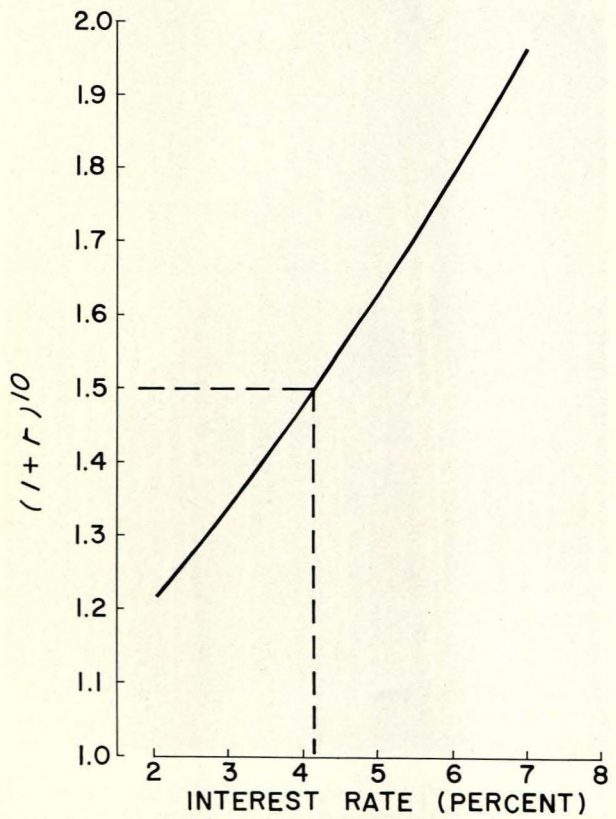

FIGURE 15. — Interest rates for known $(1+r)^{10}$. For example, the interest rate (r) for $(1+r)^{10} = 1.50$ is 4.13 percent.

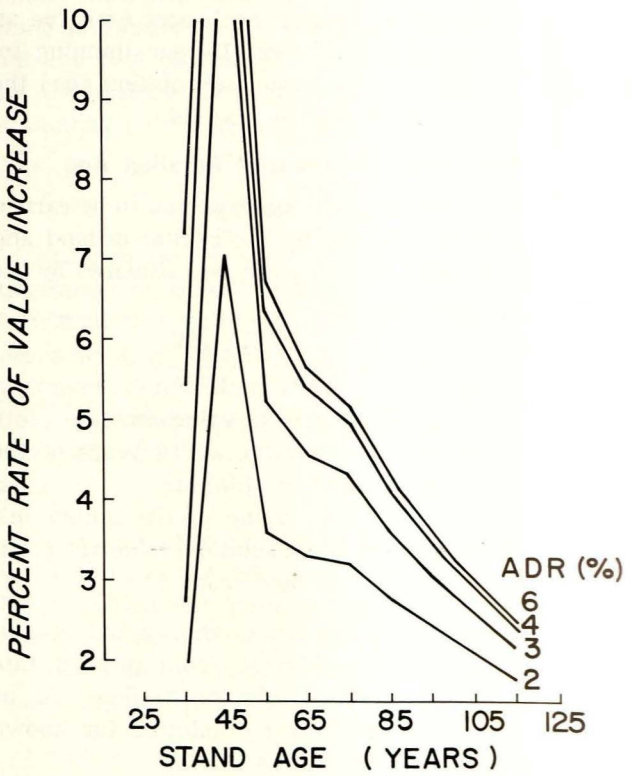

FIGURE 16. — Annual rate of value increase during the next 10 years in a red pine stand on site index 60 for alternative discount rates (ADR). Stumpage prices $20 per thousand board feet and $2 per cord, future establishment costs $40 per acre, 800 trees and 90 square feet of basal area per acre at age 25, thinned every 10 years to 90 square feet.

Varying factor (all others constant)	*Rotations may be shorter if level is—*	*Rotations may be longer if level is—*
Site index	Low	High
Initial stocking (no. of trees)	Low	High
Initial density (basal area)	High	Low
Density after thinning	High	Low
Future establishment costs	Low	High
Stumpage prices	High	Low
Alternative rates	High	Low

Except for discount rates, no single factor greatly affects rotation ages. A large difference in site or future establishment costs, for example, changes the rotation by only 10 or 20 years. However, the cumulative effect from a number of factors can be large.

Let us consider a red pine stand on site index 45, with 800 trees and 120 square feet of basal area per acre before thinning at age 25, to be thinned every 10 years to 120 square feet of basal area, with no cost of establishment, $3 per cord stumpage price, and an 8-percent alternative rate of return. This stand has an LEV of $5.30 per acre, and a financial rotation age of 25 years, the shortest rotation considered. To get the highest return on invested capital, this stand should be cut as soon as it is merchantable for cordwood.

In contrast, red pine on site index 60, with 1,600 trees and 90 square feet of basal area per acre at age 25, thinned every 10 years to 90 square feet of basal area per acre, with $80 per acre cost of establishment, $10 per thousand board feet and $1 per cord stumpage price, and a 2-percent alternative rate of return, has an LEV of --$5.60 per acre and a financial rotation age of 155 years.

Financial rotations of these two stands differ by 130 years; yet the stand conditions do not include the extremes that may be found. Neither do the costs, prices, and alternative rates of return cover the entire range that may be expected. Because financial rotations vary widely among red pine stands the same rotation should not be used for all red pine stands if the goal is to earn a high return on invested capital. Although rotation ages do vary among stands, it is also true that in any one stand under a given set of costs and prices, rotations can vary somewhat from the financial rotation age and not greatly affect estimates of LEV's. This fact can be put to good use in evaluating investment alternatives.

A good illustration of this is given by a red pine stand established on site-index-50 land at $40 per acre (fig. 17). This stand is expected to have 800 trees and 120 square feet of basal area per acre at age 25. It is to be thinned every 10 years to 90 square feet of basal area per acre with cordwood and sawtimber sold at $2 per cord and $20 per thousand board feet. The discount rate is 3 percent. Here, rotations of 25, 35, and 45 years give negative LEV's (indicating that rotations this short will not earn 3 percent on invested capital). As the rotation is lengthened, the values increase to a maximum at age 85, the financial rotation. If the rotation is extended beyond 85 years, the LEV decreases slowly but steadily.

Note that the LEV's do not vary greatly over a range of rotations. As the following tabulation shows, the LEV's lie between $47 and $50 per acre for rotation ages from 75 to 115 years.

Rotation age	*LEV*	*Percent below maximum*
65	$40.99	17.9
75	47.16	5.6
85	49.94	0.0
95	49.88	0.1
105	48.59	2.7
115	46.89	6.1
125	44.98	9.9

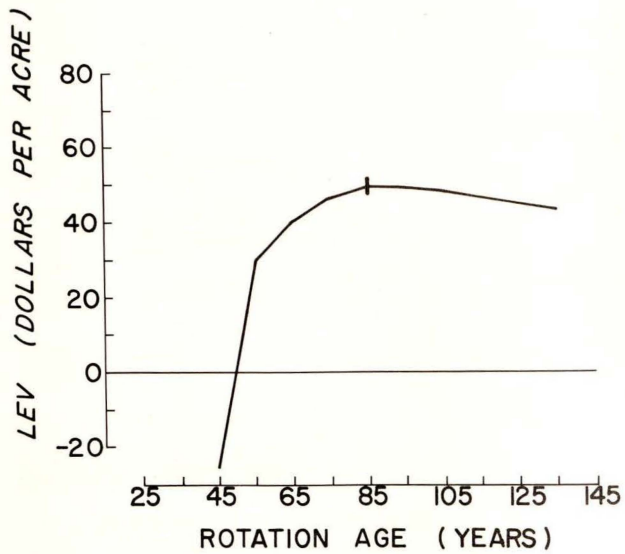

FIGURE 17. — Red pine land expectation values (LEV) vary with rotation age. Site index 50, thinned every 10 years to 90 square feet, establishment costs $40 per acre, stumpage prices $20 per thousand board feet and $2 per cord, discount rate 3 percent, 800 trees and 120 square feet at age 25.

In valuing this investment the financial rotation, 85 years, should be used; but any rotation between 75 and 115 years will give an LEV within 6 percent of the highest obtainable.

Most thinned stands of red pine follow the same general pattern: negative or low expectation values for short rotations, followed by a rapid increase to a maximum, and then a gradual decline as rotations lengthen. Under many conditions, setting the rotation within 10 or 20 years on either side of the financial rotation age will not greatly affect estimates of investment returns. Thus, it may be possible to use a common rotation age in estimating LEV's for specified situations.

For example, financial rotations in the stands in figure 18 vary from 85 years on site index 45 to 95 years on site index 60. A rotation age of either 85 or 95 years could be used for all sites, and the estimated LEV would be within 2 percent of the maximum for any site within this range, as the following tabulation shows.

Site index	*LEV for rotation age —*	
	85	*95*
45	$32.00	$31.50
50	52.10	52.00
55	74.50	75.50
60	105.10	105.90

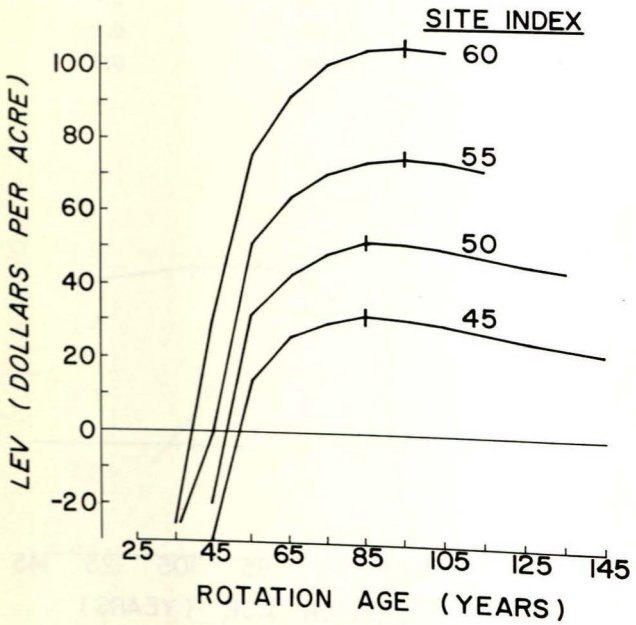

FIGURE 18. — Financial rotations in red pine stands vary with sites. Thinned every 10 years to 90 square feet, establishment costs $40 per acre, stumpage prices $20 per thousand board feet and $2 per cord, discount rate 3 percent, 800 trees and varying basal areas at age 25. LEV is land expectation value.

If stands differ in only one or two respects, a common rotation age often can be used without much error in estimating investment returns. However, if stands differ greatly in many respects, a common rotation age should be used with caution or LEV estimates may be seriously in error.

Some Suggested Financial Rotation Ages

In red pine stands grown for sale only as cordwood at constant prices and thinned every 10 years to 90 square feet, initial stand conditions have almost no effect on financial rotations and can be ignored. Cordwood volume growth is not affected by tree diameter, only by age, site, and basal area left after thinning. If all stands are thinned to 90 square feet every 10 years, as recommended, then at any given stand age the cordwood volume growth depends only upon site; and the value growth depends upon site, prices, and costs.

With a $4-per-cord stumpage price most red pine stands will have the financial rotations shown in table 1 for given sites and regeneration costs. Few will have rotations that differ from these by more than 10 years.

As this table illustrates, financial rotations are longer at lower interest rates. Higher regeneration costs also lengthen rotations, because longer rotations postpone these costs. At a stumpage price of $4 per cord, stands with regeneration costs of $40 or more will usually have a negative LEV for interest rates of 4 percent or higher, indicating that at these costs and prices the stands cannot earn this rate on invested capital. The rotations shown here are those that will maximize returns or minimize losses if stands with a negative LEV are regenerated under these conditions. If stands with a negative LEV are not to be regenerated, they will have the rotations shown in parentheses.

The rotations shown here also apply for constant stumpage prices other than $4 per cord if the regeneration cost intervals are adjusted. The $0, $40, and $80 regeneration costs for which rotations are given represent the value of 0, 10, and 20 cords respectively. For example, at a stumpage price of $2.50 per cord, the rotations shown apply for regeneration costs of $0, $25, and $50. The footnotes to the table suggest how rotation ages can be adjusted to the other changes in conditions.

Although this table is not a perfect substitute for a complete evaluation of financial maturity in

TABLE 1. — *Financial rotation ages in thinned red pine stands for all initial stand conditions.*[1] *Only cordwood sold.*[2]

Site index	Future regeneration costs per acre	Interest rate (percent)			
		2	4	6	8
	Dollars	*Years*	*Years*	*Years*	*Years*
45	0	65	45	35	35
	40	85	75(65)	65(45)	55(35)
	80	105	105(65)	95(45)	85(35)
60	0	75	55	45	35
	40	95	85(75)	65(55)	55(35)
	80	105	105(75)	95(55)	85(35)

NOTE: These rotations assume that the land will be used to grow a new crop of timber even if the LEV is negative. Rotations in parentheses assume that no new crop will be established because the LEV is negative.

1 *Thinned every 10 years to 90 square feet of basal area per acre, 400 to 1,600 trees and 90 square feet of basal area per acre before thinning at age 25. Stands with only 60 square feet of basal area at age 25 would have rotations longer by about 10 years.*

2 *Stumpage price $4 per cord. If stumpage prices increase with tree size, rotations will be longer.*

TABLE 2. — *Financial rotation ages in thinned red pine stands.*[1] *Sawtimber and cordwood sold*[2]

Site index	Age 25		Interest rate (percent)			
	Trees[3] per acre	Average d.b.h.	2	4	6	8
	Number	*Inches*	*Years*	*Years*	*Years*	*Years*
45	400	6.4	85	75	65	55
	800	4.5	95	85	75	65
	1,200	3.7	105	95	85	75
	1,600	3.2	115	105	95	85
60	400	6.4	95	85	65	45
	800	4.5	115	95	75	55
	1,200	3.7	125	105	85	65
	1,600	3.2	135	115	95	75

1 *Thinned every 10 years to 90 square feet of basal area per acre.*

2 *Stumpage price $20 per thousand board feet and $2 per cord, and regeneration costs of $20 to $80 per acre. Regeneration costs below $20 per acre will shorten rotations by about 10 years.*

3 *Number of trees per acre at age 25 after thinning to 90 square feet of basal area per acre.*

each stand at each thinning age, financial rotations determined by a detailed appraisal are not likely to differ from those shown here by more than 10 years.

In sawtimber stands, the rate of board-foot volume growth after thinning to 90 square feet is affected not only by site and age, but also by average stand diameters. Tree diameters determine the board-foot recovery from a given cubic-foot volume. Under the assumptions in this analysis, any stands with the same site index, age, and average stand diameter after being thinned to 90 square feet will have identical cubic-foot, cordwood, and board-foot standing volumes and volume growth over the next 10 years. If costs and prices also are the same, then so will be the value growth and the financial rotation (table 2).

Figure 19 shows the average diameters expected at each age in stands with the initial conditions given in table 2 if the stands are thinned every 10 years to 90 square feet. If the site, age, and average stand diameter are known for any older stand, one can use figure 19 to determine what initial conditions would have produced this kind of stand. In this way any stand, regardless of its past history, can be described by the average diameter (or number of trees with 90 square feet of basal area) at age 25 of a stand that has followed the prescribed thinning pattern.

For example, a 75-year-old stand on site index 60 with an average diameter of 13 inches has the same diameter as a stand that started out with slightly more than 800 trees per acre and 90 square feet at age 25. Such a stand will have financial rotations of about 115, 95, 75, and 55 years for discount rates of 2, 4, 6, and 8 percent (table 2), assuming the sawtimber stumpage prices and costs are within the range of the table.

Financial rotations are longer in stands grown for both sawtimber and cordwood than in stands grown only for cordwood (compare table 2 with table 1). This comes as no surprise. Once a stand is merchantable for sawtimber, at any given age the board-foot volume growth rate is higher than the cordwood volume growth rate, because not only does the cubic-foot volume increase but also the ratio of board feet to cubic feet.

Although these rotations are for a constant stumpage price of $20 per thousand board feet and $2 per cord over a range of regeneration costs from $20 to $80, these same rotations apply to other constant stumpage prices with a range of regeneration costs equal to the value of from 1 to 4 thousand board feet. For example, at $30 per thousand board feet and $3 per cord they apply for regeneration costs from $30 to $120 per acre; at $10 per thousand board feet and $1 per cord, for costs from $10 to $40 per acre. The ratio of sawtimber prices to cordwood prices can vary widely without much effect on rotations.

Price increases over time, whether from a change in stand characteristics or an increase in price levels, will tend to lengthen rotation ages. In one of the markets evaluated, prices rose $1 per thousand board feet for every inch increase in diameter. Table 3 shows financial rotations for this market. However, even such a sizable price increase, which often amounted to $2 or more per thousand board feet every 10 years, seldom lengthened rotation ages by more than 10 years (compare table 3 with table 2).

If stumpage prices are expected to increase at some given rate over time, financial rotations should be adjusted to reflect this fact. This can be done by subtracting the annual percent rate of price increase from the discount rate used (the

TABLE 3. — *Financial rotation ages in thinned red pine stands.*[1] *Sawtimber and cordwood sold at prices increasing with average stand diameter*[2]

Site index	Age 25		Interest rate (percent)			
	Trees[3] per acre	Average d.b.h.	2	4	6	8
	Number	*Inches*	*Years*	*Years*	*Years*	*Years*
45	400	6.4	105	85	75	55
	800	4.5	115	95	75	65
	1,200	3.7	115	95	85	75
	1,600	3.2	125	105	95	85
60	400	6.4	95	95	75	65
	800	4.5	115	105	85	75
	1,200	3.7	145	115	95	75
	1,600	3.2	165	125	105	85

1 *Thinned every 10 years to 90 square feet of basal area per acre.*

2 *Stumpage prices $(DBH + 5)$ per thousand board feet, $(\frac{1}{2}DBH - 1)$ per cord.*

3 *Number of trees per acre at age 25 after thinning to 90 square feet of basal area per acre.*

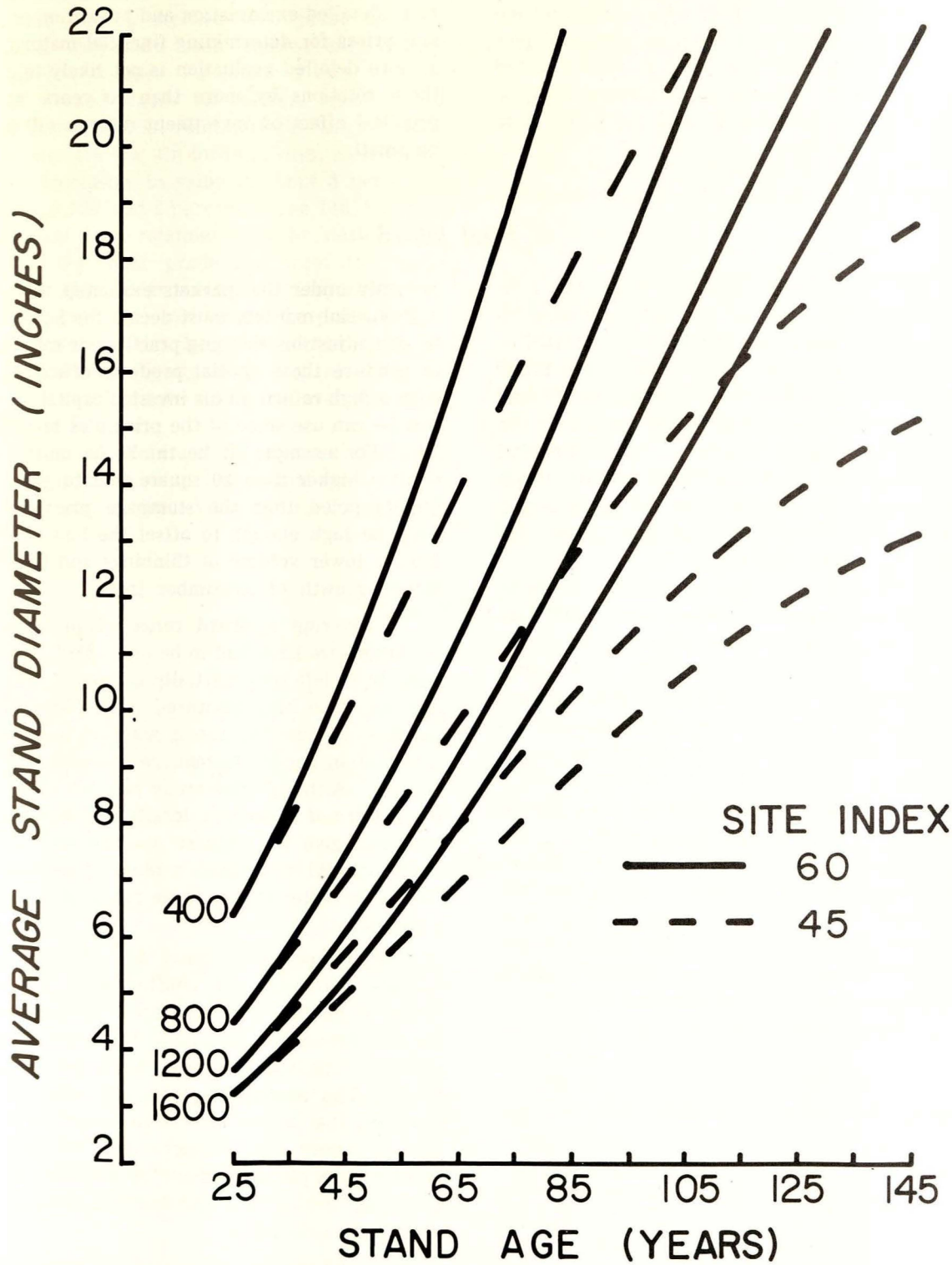

FIGURE 19. — Average diameters of red pine stands thinned to 90 square feet of basal area per acre at age 25 and every 10 years thereafter; for stands on site index 45 and 60, and with from 400 to 1,600 trees per acre after thinning at age 25.

alternative rate) to get an adjusted discount rate. If prices are expected to increase at 2 percent annually and the alternative discount rate is 6 percent, 4 percent should be used as the adjusted discount rate for estimating financial rotations. The slight error in this approximation will have little effect on rotations.

As noted before, these tables do not replace a more detailed examination and projection of yields and prices for determining financial maturity. But a more detailed evaluation is not likely to change these rotations by more than 10 years, and the practical effect on investment returns will usually be small.

A Final Word

The aim of this paper was to explain how rotation ages and stand density left after thinning — two factors that the forest manager can control — affect investment returns from growing red pine.[9] It has demonstrated that red pine stands thinned every 10 years to 90 square feet of basal area per acre will earn a higher return on invested capital than will stands thinned to a higher density. It has suggested financial rotations for red pine grown only for cordwood and for red pine grown for sawtimber and cordwood jointly.

All of the examples and conclusions given in this paper are based on growth and yield data developed from many research plots in pure stands of red pine in northern Minnesota. The stands evaluated here are constructed from these growth and yield data. They are not actual stands. Because these data are averages they will not necessarily apply to any one single stand over a particular period of time, but are what can be expected from several similar stands over a long time. Although these data are confined to northern Minnesota and do not include the better quality sites, the same general conclusions are likely to hold over the entire range of red pine. Similar recommendations for low-density management are being made for other pine species throughout the world.[10]

It was not possible to consider all of the special products such as posts, poles, piling, and mine timbers that can be produced in red pine stands. Any management recommendations made here apply only under the markets evaluated. A forester with special markets must decide for himself how he can adjust his thinning practices or rotation age to produce these special products efficiently and earn a high return on his invested capital. In doing this he can use some of the principles brought out here. For example, if he thinks he must keep a density higher than 90 square feet to grow high-quality poles, then the stumpage price per pole must be high enough to offset the loss in income from a lower volume of thinnings and the slower future growth of sawtimber trees.

In covering a broad range of problems and conditions we have had to be brief. Many questions have been left only partially answered, and some may not have been answered at all. However, this paper does give the forest manager some of the information needed to manage red pine stands efficiently. Although this study may not have found the pattern of basal area density left after thinning that will give the highest possible return on invested capital, it suggests a thinning schedule that clearly is better than a wide range of alternative schedules.

The 90-square-foot basal area density recommended here does not conflict with the density range of 90 to 110 square feet recommended by the U.S. Forest Service (1965) timber management guide for the red pine type in the North Central Region. The conclusions from this study suggest, however, that if red pine is to be grown for saw logs or veneer logs, no more than 90 square feet of basal area per acre should be left after thinning if capital invested in growing red pine is to be used most efficiently.

Most of the sawtimber rotations suggested here are shorter than the 120 to 140 years recommended by the timber management guide for the red pine type. However, the present older stands of red

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9 *A later paper will show how to calculate investment returns for specific red pine timber-growing opportunities, and how to use present values and rates of return to compare investment alternatives and answer questions about timber-growing investments.*

10 *For example, see Hiley (1958) on South African pine plantations, Wiksten (1960) and Andersson (1963) on Scots pine (Pinus sylvestris L.) in Sweden, and Lewis (1962) on Pinus radiata (D. Don) stands in Australia.*

pine to which these rotation ages refer undoubtedly were densely stocked throughout most of their life. They have been thinned only during the last few decades. As tables 2 and 3 show, densely stocked stands on medium sites (50 to 60) do have financial rotations this long if alternative rates are low. On medium sites, such stands are still increasing in value at about 3 percent a year at age 120, and 2 percent at age 140. Furthermore, these long rotations may be desirable to maintain sawtimber production from the small acreage of these older stands until they can be replaced by plantations old enough to produce sawtimber. Rotations this long are not likely to be used in the more lightly stocked plantations, because the earning rate would be even lower in plantations this old.

Earning a high return on invested capital is not the only objective of timber management, but it is an important one. Although other objectives may be given a higher priority at some places and at some times, it is difficult to justify a plan of management that accepts an investment return lower than could be obtained by some other plan unless the added benefits clearly outweigh the loss in income and increased timber production costs.

Throughout the discussion we have tried to show how to get the highest investment return from individual red pine stands. This is only a first step towards getting the highest investment return from all timber-growing activities in an organization; but it is a necessary step. Unless the costs and returns from growing timber in each stand are evaluated, we are in a poor position to evaluate an entire forest property. Until more information on other forest types is available over a wider range of sites and stand densities, at least it is possible to manage red pine stands to insure high investment returns.

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